

# Scaling Public Concerns of Electromagnetic Fields Produced by Solar Photovoltaic Arrays

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## Introduction

In our modern society electricity is vital to our health, safety, comfort and well-being. While our daily use of electricity is often taken for granted, public concern has arisen about potential adverse health effects from electric and magnetic – electromagnetic – fields (EMFs) produced by our use of electricity. The purpose of this paper is to give an overview of the sources and scale of electric and magnetic fields and provide an understanding of the current science about potential associated health risks. In addition, included is an evaluation of the sources and scale of EMFs to be produced by the proposed West Linn Solar highway photovoltaic solar array.

### **KEY FINDINGS**

- People are constantly exposed to electric and magnetic fields (EMFs) from a variety of natural and human-made sources.
- The current scientific consensus is that no causal relationship exists between exposure to low-level power frequency EMFs and any adverse health effects including childhood cancer.
- Protective guidelines exist limiting public and occupational exposure to harmful short-term exposures to very high levels of EMFs that can be harmful to human health.
- Health protection guidelines established by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) suggests that the general public not be exposed to static magnetic fields in excess of 4 million milligauss or power frequency magnetic fields in excess of 830 milligauss.
- Under controlled testing conditions, the largest string of solar panels at the proposed West Linn Solar Highway Project could theoretically produce a static magnetic field of 1,697 milligauss at a distance of three feet from the string conduits. This is less than one twentieth of one percent (<.05%) of the ICNIRP's threshold for exposure to static magnetic fields for the general public.
- The type of power inverter proposed for use in the West Linn project could theoretically produce a maximum power-frequency magnetic field of approximately 344 milligauss at a distance of three feet away. This is less than half of the ICNIRP's threshold for exposure to power-frequency magnetic fields for the general public.
- At a distance of ten feet the field strength from the power inverter would fall to approximately 3 milligauss — a level comparable to common household appliances. The proposed locations for power inverters at the West Linn site are more than 250 feet away from the closest residences.
- The potential theoretical EMFs produced by the proposed West Linn Solar Highway photovoltaic array would likely be indistinguishable from background levels produced by other human and natural sources at the perimeter of the site's security fence and therefore are not a concern to public health for neighboring residences.

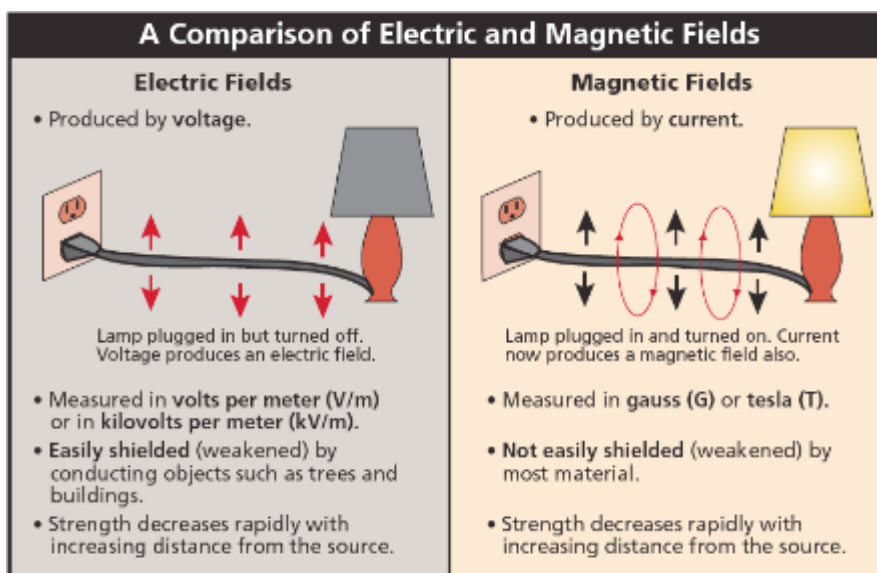
## The Basics of Electric and Magnetic Fields

### Sources of electromagnetic fields

Electromagnetic fields (EMFs) are invisible fields of electric and magnetic force associated with the movement of charged particles. EMFs are produced by natural sources, such as the movement of liquid magma below the earth's crust as well as human-made sources, most often involving the production and distribution of electricity. EMFs also arise from the operation of electronic equipment and appliances in our homes and businesses such as computers, televisions and refrigerators.

EMFs are comprised of both electric and magnetic fields. In electric power systems, voltage, defined as the force that causes electrons to flow in a wire or cable, produces electric fields. The strength of an electrical field is measured in units of volts per meter (V/m). Current produces magnetic fields (defined as the rate at which electrons flow across a conductor). The strength of a magnetic field is typically measured in units of tesla (T), gauss (G) or milligauss (mG). One milligauss is 1/1,000<sup>th</sup> of a gauss and one gauss is 1/10,000<sup>th</sup> of a tesla.

To illustrate (see Figure 1), the cord of a lamp plugged into a wall socket but turned off will generate an electrical field from the voltage in the line. When the lamp is turned on, electrical current flows through the cord creating a magnetic field in addition to the electrical field.



**Figure 0 Electric Fields versus Magnetic Fields**  
*Courtesy of National Institute of Environmental Health Sciences*

### Field strength, shielding and distance

The strength of electric and magnetic fields is directly related to the magnitude of the voltage and current present in the system — the stronger the voltage and current the stronger the electric and magnetic fields.

Notably, the intensity of both electric and magnetic fields weakens at an exponential rate the greater the distance from the source. The precise rate at which the field weakens is dependent on the specific configuration of the electrical equipment involved. The strength of electric fields are further weakened, or shielded, by common materials including buildings, trees, fences and walls. Most materials, on the other hand, do not diminish magnetic fields. Given this difficulty in shielding most scientific inquiry into potential biological or human health effects has focused on magnetic fields<sup>1</sup>. For this reason the information presented in this paper also focuses on magnetic fields.

## *Potential health concerns from exposure to magnetic fields*

### **"Power frequency" versus "static" magnetic fields**

The magnetic fields created by alternating current (AC) electric systems, like those associated with the electricity grid, are often referred to as "power frequency" fields. If sufficiently large, power frequency magnetic fields can induce a current in the human body large enough to cause muscle and nerve stimulation that can result in headaches and pain<sup>2</sup>.

The magnetic fields created by DC electric systems, such as battery-powered electronics, are commonly referred to as "static" fields, since the current in the system does not vary over time. In most circumstances static magnetic fields do not induce electric currents in humans and are not a health concern.<sup>3</sup>

### **Health protection guidelines for exposure to high level magnetic fields**

While neither the United States government or the State of Oregon have established regulations governing exposure to power frequency magnetic fields, several organizations have sought to develop exposure guidelines in order to protect the general public and workers against potential adverse health effects.

The most rigorous exposure guidelines are those developed by the International Commission on Non-Ionizing Radiation Protection (ICNIRP). For the general public, the ICNIRP has established a threshold for acute exposure of 830 milligauss for power frequency magnetic fields. It is important to note that these guidelines were established with a large safety margin and that exposure above the guideline's established limits is not necessarily harmful to human health. In fact, the ICNIRP's occupational exposure guidelines for power frequency magnetic fields are substantially higher at 4,170 milligauss<sup>4</sup>.

The ICNIRP's health protection guidelines for static magnetic fields suggest that the general public not be exposed to fields in excess of 4 million milligauss. This limit is increased to up to 80 million milligauss for certain medical procedures such as magnetic resonance imaging (MRI)<sup>5</sup>.

### **No causal relationship between low level power frequency magnetic fields and adverse health effects**

Extensive reviews of the scientific and medical literature from studies conducted by the National Institute of Environmental Health Science,<sup>6</sup> the National Academy of Sciences<sup>7</sup> and the World Health Organization<sup>8</sup> all conclude that current scientific evidence does not point to a causal relationship between the existence of health consequences and exposure to low level electromagnetic fields or EMFs.

While some epidemiological studies show a weak association between chronic exposure to low levels of power frequency magnetic fields (above 3 to 4 milligauss on a 24-hour time-weighted basis) and a small increased risk for childhood leukemia, these studies have largely focused on the potential relationship between childhood cancers and proximity to high voltage transmission lines. However, laboratory studies have failed to demonstrate a reproducible effect that is consistent with the hypothesis that magnetic fields cause or promote cancer. For this reason, scientists do not generally believe that a cause and effect relationship exists between magnetic field exposure and childhood leukemia.<sup>9</sup>

### **Precautionary approach**

Despite the scientific consensus regarding the causality between exposure to low levels of power frequency magnetic fields (above 3 to 4 milligauss on a 24-hour time-weighted basis) and adverse human health effects, a number of organizations have encouraged a precautionary approach aimed at minimizing the potential risk by minimizing public exposure to low frequency magnetic fields. Such prudent avoidance strategies include siting high voltage transmission lines away from schools and childcare facilities, special configurations for power line conductors and buffer zones along high voltage transmission right-of-ways.<sup>10</sup>

## Magnetic field levels in homes and workplaces

People are constantly exposed to magnetic fields in homes, workplaces and communities from the generation, transmission and use of electricity in common appliances and electronics. In fact, certain appliances can produce sizable magnetic field levels that in some cases even exceed the fields produced underneath high voltage power lines. However, these sources are not generally considered a risk factor because the duration of exposure is typically short-lived and the strength of these fields diminishes rapidly with distance.

In everyday circumstances most people do not experience magnetic fields that exceed guidelines for acute exposure. In the United States, most people are exposed to magnetic fields that average less than 2 milligauss on a 24-hour time-weighted basis.<sup>11</sup>

The table below (see Table 1) shows the magnetic field strength of some common appliances and electronics. At a distance of three to five feet, strength of the magnetic fields generated by most household appliances is indistinguishable from the typical amount a person might encounter even if the source was not present.<sup>12</sup>

**Table 1: Typical Magnetic Fields from Common Appliances**

Source	Field strength at 12 inches (milligauss)	Field strength at 3 feet (milligauss)
Coffee Maker	.09 to 7.3	0 to .61
Copy machine	.05 to 18.38	0 to 2.39
Television	1.8 to 12.99	.07 to 1.11
Vacuum Cleaner	7.06 to 22.62	.51 to 1.28
Microwave oven	.59 to 54.33	.11 to 4.66
Computer monitor	.2 to 134.7	.01 to 9.37

Source: California Department of Health Services

## Magnetic fields from the electricity grid

Much of the public concern regarding exposure to magnetic fields has focused on components of the electricity grid, especially high voltage transmission lines. While certain components of the electricity grid can produce significant magnetic field levels, these sources do not generally pose a significant risk because the duration of exposure is typically short-lived and the strength of the fields diminishes rapidly with distance.

The strength of magnetic fields produced by the various components of the electricity grid depends on several factors including: the number of wires or conductors, the geometric arrangement of the conductors and the amount of current carried by the line.<sup>13</sup>

High voltage transmission lines transfer the electricity produced at central station power plants and hydroelectric dams to the population centers where the electricity is consumed. Transmission lines usually terminate at distribution substations where the voltage is reduced to a level suitable for local distribution. From the distribution substation, low voltage distribution lines deliver electricity to industrial, commercial and residential customers. Local distribution transformers further reduce voltage to the level appropriate for the final distribution of power to a given customer.

High voltage transmission lines tend to produce larger magnetic fields than distribution lines because they carry more current. The strength of a magnetic field is directly proportional to the amount of current — so larger lines carrying more current have stronger fields. The amount of current varies with changes in use of electricity. The more electricity consumed the greater the current.

The table below (see Table 2) shows the typical magnetic field strength beneath power lines at various distances.<sup>14,15</sup>

**Table 2: Typical Magnetic Fields from Electric Power Lines**

Source	Field strength beneath power line (Milligauss)	Field strength at 200 feet (Milligauss)
500 kilovolt transmission line	86.7	3.2
230 kilovolt transmission line	57.5	1.8
115 kilovolt transmission line	29.7	0.4
12 kilovolt three-phase distribution line	14	0

Sources: National Institutes of Environmental Health and PPL Electric Utilities Corporation

Electric power substations and transformers necessarily make use of equipment that can produce strong localized magnetic fields. However, the application of electric safety codes result in the general public being excluded from these sources by fence, enclosure or height (distance). Beyond these exclusions, the EMFs produced by the substation equipment are typically indistinguishable from background levels produced by other human and natural sources.<sup>16</sup>

## Magnetic fields from photovoltaic solar arrays

The basic building block of a photovoltaic power system, or solar array, is the solar cell. Individual solar cells in turn are connected together by conductors to form larger units called modules or panels. A collection of panels interconnected in an electrical series is called a series string. Often several series strings will also be connected together in parallel to create a parallel string, in order to optimize the electrical output of a solar array.

Photovoltaic solar arrays convert the energy from sunlight into direct current electricity. The amount of direct current present in a given parallel string is equivalent to the sum of the current in each series string. In turn, the amount of direct current in a series string is determined by the amount of solar energy absorbed by the modules. As with all series circuits, the direct current through each module is the same regardless of its position in the series string. The maximum direct current a given solar panel can produce varies by manufacturer. At night when no sunlight is absorbed no current flows through the array or any of the other system components.

In order to supply usable electricity to the electric grid, the direct current electricity generated by a solar power system must be converted into alternating current. This is accomplished with an electronic device called a power inverter, or power conditioning unit. Once the electricity is converted from direct current to alternating current, it can be placed onto the local electricity distribution grid through a grid interconnection.

### Static magnetic fields from parallel string solar panels

The direct current flowing through a string of solar panels creates a static magnetic field. The International Commission on Non-Ionizing Radiation Protection (ICNIRP) exposure limit guidelines *suggest that the general public not be exposed to static magnetic fields in excess of 4 million milligauss*. The practical limits of solar power system design ensures that the strength of any static magnetic fields from solar arrays would not approach the ICNIRP's exposure limits.

The proposed West Linn Solar Highway project may feature up to twelve sets of parallel strings. The largest parallel string may be comprised of as many as 100 series strings, each with up to fourteen 230-watt panels with a maximum current of 7.76 amperes of direct current. Under controlled testing conditions, this parallel string configuration could theoretically generate 776 amperes of direct current and produce a static magnetic field of approximately 1,697 milligauss at a distance of three feet from the largest solar array.<sup>1</sup>

<sup>1</sup> Static magnetic field strengths calculated using the Biot Savart Law for the magnetic field of a long, straight wire:  $B = K \frac{I}{r}$  where:  $B$  is magnetic field strength;  $I$  is the value of electrical current;  $r$  is the distance between the wire and the point of interest and  $K$  is a known constant. For additional understanding visit <http://www.cdc.gov/niosh/pdfs/91-111-g.pdf>.

This is less than one twentieth of one percent (<.05%) of the ICNIRP's exposure guidelines for static magnetic fields. Moreover, at a distance of ten feet, the field strength would fall to approximately 509 milligauss and would be largely indistinguishable from the Earth's natural static magnetic field of approximately 500 milligauss. Notably, the proposed location for the solar arrays at the West Linn site is more than 200 feet away from the closest residences.

### **Power frequency magnetic fields from power inverters**

Power inverters are the most common source of power frequency magnetic fields in photovoltaic systems.<sup>17</sup> The strength of power frequency magnetic fields from a power inverter is directly related to the amount of alternating current that the inverter supplies. Every inverter has a maximum amount of alternating current output that it can supply on a continuous basis. While it is highly uncommon for inverters to continuously operate at this maximum, given daily and seasonal variability of solar irradiance, the threshold can be used to estimate the maximum potential magnetic field associated with the operation of a given inverter.

The number of inverters in a solar array will vary depending on the specifications of the equipment involved, but a common configuration for a large grid-tied system is to utilize one inverter for each parallel string. The current design of the proposed West Linn Solar Highway project may feature as many as twelve 260-kilowatt inverters, each with a rated maximum alternating output capacity of 301 amperes.

The maximum inverter output of 301 amperes of alternating current could theoretically produce a time-varying magnetic field of approximately 344 milligauss at three feet away.<sup>2</sup> This is less than half (<50%) of the ICNIRP's exposure guideline for the general public.

Moreover, at a distance of ten feet the field strength would fall to approximately 3 milligauss — a level comparable to common household appliances. Notably, the proposed location for the power conditioning units at the West Linn site are more than 250 feet away from the closest residences.

### **Power frequency magnetic fields from electric grid interconnection**

In the case of a utility-scale, grid-connected solar array, once the electricity is converted from direct current to alternating current it is placed onto the existing local electricity distribution grid via an extension from a local distribution line.

The exact point of interconnection between the West Linn Solar Highway project and Portland General Electric's (PGE) local grid is yet to be determined. However the closest potential point of interconnection is along PGE's existing 13-kilovolt distribution lines that run parallel to South Salamo Road. Under any scenario the interconnection lines would not cross any residential properties.

The magnetic fields from interconnection lines would produce magnetic fields similar to those of the existing distribution grid infrastructure.

### **Intentionally conservative assumptions**

Two key assumptions underlying the estimates of static and time-varying magnetic fields are intentionally conservative. First, the estimates are based on the nameplate capacities of the equipment involved. Under real world conditions it is unlikely that the equipment will reach these maximum thresholds. Second, the estimates do not account for potential cancelling effects resulting from certain system geometries. According to the laws of physics, the strength of a given magnetic field may be largely cancelled out by the presence of the magnetic field

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<sup>2</sup> Static magnetic field strengths calculated using the Biot-Savart law for the magnetic field of a loop current like those found in solar inverters: source:  $B = \frac{KIa^2}{r^3}$  where:  $B$  is magnetic field strength;  $I$  is the value of electrical current;  $a$  is the radius of the loop in feet,  $r$  is the distance between the wire and the point of interest and  $K$  is a known constant. In this calculation it is assumed that the radius of the loop is 1 foot. For additional understanding visit <http://www.cdc.gov/niosh/pdfs/91-111-g.pdf>.

created by another conductor with current flowing in the opposite direction. No attempt was made to account for these canceling effects in these estimates.

### Summary of magnetic fields from proposed West Linn Solar Highway project

The strength of magnetic fields resulting from the proposed West Linn Solar Highway photovoltaic array do not approach the levels considered a risk to human health (see Table 3 below). Additionally, at the perimeter of the site's security fence the strength of these magnetic fields would be largely indistinguishable from background levels produced by other human and natural sources.

**Table 3: Potential Magnetic Field Strength from Various Components of West Linn Solar Array**

Source	Field Type	Field strength at 3 ft. (Milligauss)	Field strength at 10 ft. (Milligauss)	Corresponding ICNIRP exposure limit for the general public (Milligauss)
Parallel string of PV modules	Static	1,697	509	4,000,000
DC to AC power inverter	Power frequency	344	3	830
Grid interconnection	Power frequency	14	n/a	830

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